Electric Power Feeding Room for Notebook Computers - Analysis of SAR and Internal Electric Field in Human body -

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Abstract

This paper presents an energy transmission system over a long distance for a wireless notebook computer. The biological effects of the electromagnetic field are analyzed using a simulator. At the same time, energy of 50 W, which is the necessary maximum energy for a notebook computer, can be safely transmitted.

Keywords : Wireless SAR Internal electric field

1. Introduction

Recently, much progress has been made in the development of electric appliances, which are necessary and indispensable in daily life. However, AC adapters that supply electric power becomes complex as the number of electronic appliances increases. In addition, problems such as loose connections and ground leakage in the power supply terminal of the cables have to be solved. To resolve these issues, a wireless electric power transmission system based on the electromagnetic field can be employed. Moreover, this method offers the advantage that power can be supplied to the electric appliances unattended. The near-field wireless electric power transmission system uses the principle of resonance, and electric power can be effectively transmitted using this method if the distance of transmission is long [1]. The coils used have been actively researched [2][3]. Additionally, wireless electric power transmission systems for electronic appliances have been studied to improve the transmission efficiency (90%) [4]. However, the distance of transmission is short (-15 mm). In medical equipment research, the biological effects are routinely considered [5]; in addition, the targeted transmission distance is short (10-150 mm). Here, we examine the biological effects of the electromagnetic field when the transmission distance is long. In this paper, we assume that the distance for energy transmission for a wireless notebook computer is long. The biological effect of the electromagnetic field is evaluated by the specific absorption rate (SAR) and the internal electric field. In general, the SAR is often used as a thermal effect index. The internal electric field is also often used as an index of the stimulant action. The guidelines for the SAR and the internal electric field are provided by the International Commission on Non-Ionizing Radiation Protection [6] for the frequency range of 0.1–10 MHz. The evaluation of the biological effect is carried out by comparing the results of the SAR and the internal electric field with the guidelines listed in Tables 1 and 2. With software FEKO, the analysis of the transmitting efficiency is carried out using the moment method, and the analysis of the biological effect is carried out using the finite element method.

TABLE 1 : Basic restrictions of SAR

Exposure characteristic	Whole body average SAR [W/kg]	Localized SAR head and trunk [W/kg]
Occupational exposure	0.4	10
General public exposure	0.08	2

TABLE 2 : Basic restrictions of internal electric field

Exposure characteristic	Internal electric field (Ocupational exposureCNS tissue of the head) [V/m]	Internal electric field (All tissues of head and body) [V/m]
Occupational exposure	2.7×10^{-4}	2.7×10^{-4}
General public exposure	1.35×10^{-4}	1.35×10^{-4}

2. Analytical Model of Transformer

Fig. 1 shows the layout of the electric power transmission system used in this research. The transmitting coil is implanted in the floor, and the receiving coil is implanted in the notebook computer. The transmitting coil in the floor generates a magnetic field, and the receiving coil receives the electric power. As a result, we can charge the notebook computer's battery from anywhere in the room. The numerical analysis models for each coil are shown in Fig. 2(a). These coils are of the solenoid type. The transmitting coil has a diameter of 960 mm (fixed value), a pitch of 1 mm (fixed value), a thickness of h_1 (variable), and a wire diameter of 4 mm (fixed value). The thickness is varied because the pitch should remain constant. To make the coil resonate (Fig. 2(a)), a capacitor is connected in series. The receiving coil has a diameter of 79.6 mm (fixed value), a thickness of h_2 (fixed value), and a wire diameter of 0.4 mm (fixed value). The thickness is 10 mm because it is assumed that the receiving coil is implanted in the notebook computer. A capacitor is connected in series. The load resistance (9.5 Ω) assumes that the notebook computer is also connected. Initially, the transmitting coil and the receiving coil have 2 turns (n_1) and 6 turns (n_2), respectively. The number of turns of each coil are increased by multiplying it with numbers with a maximum of 15. The wire material of each coil is copper with an electric conductivity $\sigma = 5.8\times10^{-7}$ [S/m]. The mesh size of the transmitting coil is 10 mm, and the mesh size of the receiving coil is 5 mm (wire segment length in analysis). A simple human body model for the numerical analysis is shown in Fig. 2(b). To confirm the SAR and the internal electric field, a simple model of the human body was considered. The human body is modeled as a cylinder, an ellipsoid, and a sphere. The body is modeled as a cylinder with a diameter of 300 mm and a height of 950 mm. The head is modeled as a sphere with a diameter of 240 mm. The arm is modeled as an ellipsoid with a diameter of 35 mm and both hands are at a distance of 100 mm. The distance between the receiving coil and the hands is h_3. The distance between the transmitting coil and the body is h_4. We analyzed the SAR and the internal electric field in the case of h_3 = 30 mm and h_4 = 50 mm, and h_3 = 30 mm and h_4 = 50 mm. One hand is located right above the receiving coil. The biomedical tissue of the simple human body has only a muscle. This paper uses the conductivity and relative permittivity values for muscles (Table 3) as defined by the IFAC Institute for Applied Physics [7]. The mesh size of the human body is 200 mm (tetrahedral edge length).

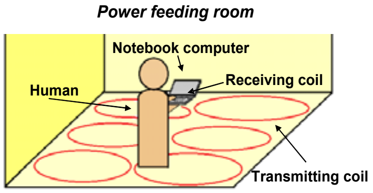
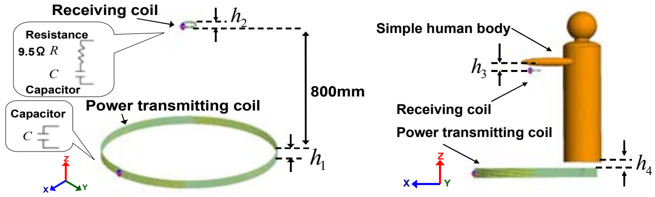


Fig. 1 Assumption of electric power transmission system in this paper



(a) (b)

Fig. 2 Analytical model of the transformer

TABLE 3 : Conductivity and Relative Permittivity of muscle tissue

Frequency [kHz]	Conductivity [S/m]	Relative permittivity
400	0.43	4339
500	0.45	3647
1350	0.52	1304
1550	0.53	1111

3. Analytical Result

The results of the analysis carried out for only the coils are shown in Fig. 3. Resonance is used in each measurement point by the transmitting coil and receiving coil. The maximum efficiency of the electric power transmission is 40%. We paid attention to the four results with the maximum effect (40%), and we named them accordingly. In "Model 1," the resonance frequency is 400 kHz and the number of multiple coil turns is 15 (n_1 = 30, n_2 = 90). In "Model 2," the resonance frequency is 500 kHz and the number of multiple coil turns is 13 (n_1 = 26, n_2 = 78). In "Model 3," the resonance frequency is 1.35 MHz and the number of multiple coil turns is 8.5 (n_1 = 17, n_2 = 51). In "Model 4," the resonance frequency is 1.55 kHz and the number of multiple coil turns is 7 (n_1 = 14, n_2 = 42).

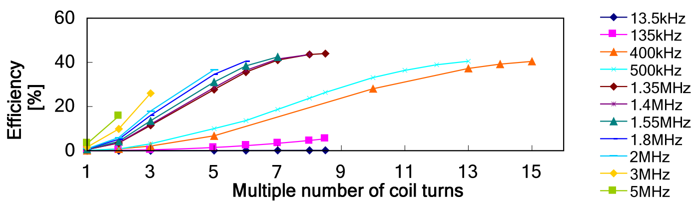
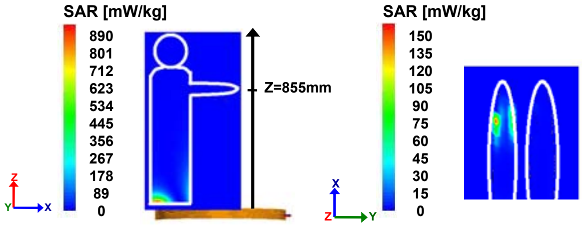


Fig. 3 Relationship between multiple number coil turns and efficiency

A. Whole body average SAR and localized SAR

The localized SAR distribution of the simple human body is similar in each model (in the case of h_3 = 30 mm, h_4 = 50 mm, and in the case of h_3 = 10 mm, h_4 = 3 0 mm). As an example, the localized SAR distribution of the simple human body in "Model 1" is shown in Fig. 4 (in the case of h_3 = 30 mm, h_4 = 50 mm). Fig. 4(a) is the localized SAR distribution of the x-z plane through the analysis model's central axis and (b) is the localized SAR distribution of the x-y plane for z = 855 mm. These results show that the localized SAR is large near the coils, and its maximum value appears in the body at a distance of 50 mm from the transmitting coil. The SAR is not large for the one hand that is located right above the receiving coil. The comparison between the SAR values and the guidelines is shown in Fig. 5. In this models, the whole body average SAR is an extreme value that is compared to the guidelines. Therefore, the whole body average SAR is used in Fig. 5. As a result, the SAR gets larger as the resonance frequency increases. At h_3 = 30 mm and h_4 = 50 mm and at h_3 = 10 mm and h_4 = 30 mm, an energy of 50 W, which is the necessary maximum energy for the notebook computer, can be transmitted by "Model 1" and "Model 2" in the case of general public exposure and by all the models in the case of occupational exposure.



(a) (b)

Fig.4 The localized SAR distribution of the human body in Model 1

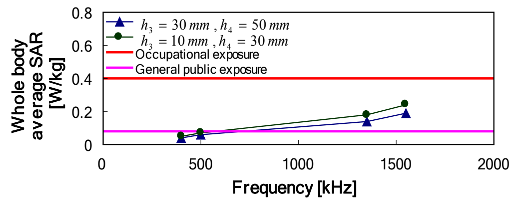
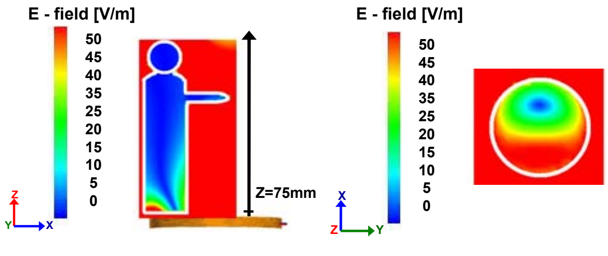


Fig.5 Comparison between limiting value and analytical result when 50W is transmitted (Whole body average SAR)

B. Internal electric field

The internal electric field distribution of the simple human body become similar in each model (in the case of h_3 = 30 mm and h_4 = 50 mm, and in the case of h_3 = 30 mm and h_4 = 50 mm); this was true in the case of the localized SAR as well. For example, the internal electric field distribution of the simple human body of "Model 1" is shown in Fig. 6 (in the case of h_3 = 30 mm and h_4 = 50 mm). Fig. 6(a) shows the internal electric field distribution of the x-z plane through the analysis model's central axis and (b) is the internal electric field distribution of the x-y plane for z = 75 mm. As in the case of the SAR, these results show that the internal electric field is large near the coils and that its maximum value appears in the body at a distance of 50 mm from the transmitting coil. The comparison between the results of the internal electric field and the guidelines is shown in Fig. 7. The maximum value of the internal electric field gets larger as the resonance frequency increases. In the case of h_3 = 30 mm and h_4 = 50 mm, these results show that all models can safely transmit 50 W, which is the necessary maximum energy for the notebook computer in both the cases. However, in the case of h_3 = 10 mm and h_4 = 30 mm, 50 W can be safely transmitted by "Model 3" and "Model 4" in the case of general public exposure and by all the models in the case of occupational exposure.



(a) (b)

Fig.6 The internal electric field distribution of the human body of Model 1

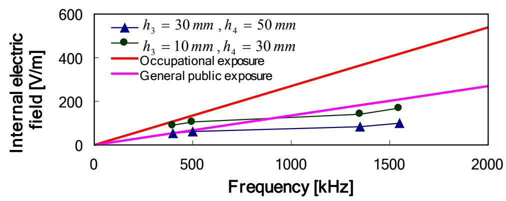


Fig.7 Comparison between limiting value and analytical result when 50W is transmitted (internal electric field)

C. Electric power that can be transmitted

In the SAR, the electric power that can be transmission in consideration of the guideline is shown in TABLE 4. These value are results of comparing the SAR (Fig. 5) with the guideline (TABLE 1) when assuming that the SAR is proportional to the transmitted power. Here, the whole body average SAR is used because the whole body average SAR is a severe value than the localized SAR. For the some models used by this analysis, these results show that the larger electric power can be transmission from 50W that is necessary maximum energy of notebook computer. Considering the guideline of the general public exposure, because this system is the one using it domestically, the model whom can be used is limited to "Model 1" and "Model 2".

TABLE 4 : Electric power that can be transmitted

Model name	Resonance frequency [kHz]	Electric power that can be transmitted [W] (General public exposure)	Electric power that can be transmitted [W] (Occupational exposure)
$h_3 = 30mm, h_4 = 50mm$			
Model 1	400	91.1	449.4
Model 2	500	68.2	340.5
Model 3	1350	31.5	143.7
Model 4	1550	21.0	105.2
$h_3 = 10mm, h_4 = 30mm$			
Model 1	400	74.1	365.6
Model 2	500	53.7	267.9
Model 3	1350	22.9	113.9
Model 4	1550	16.4	82

4. Conclusion

We analyzed the SAR and the internal electric field in biological tissue surrounding the coils by assuming that the distance of the wireless energy transmission for the notebook computer was 800 mm. According to the results, in the case of general public exposure, considering the guidelines for the SAR and the internal electric field, only "Model 1" and "Model 2" can transmit 50 W for h_3 = 30 mm and h_4 = 50 mm. Therefore, as Fig. 3 shows, it is understood that a low resonance frequency is adequate, and this means that the number of coils turns will increase. However, in the case of occupational exposure, considering the restriction imposed on the values of the SAR, it might be possible to use the system to charge electronic appliances other than a notebook computer because more than 50 W can be transmitted.

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